Surface Flammability of Fire-Retardant and Conventional Paint Assemblies

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Introduction

The results of a previous study [1] have shown that paints and other thin coverings applied to a flammable base material can provide a new surface of substantially lower flammability than that of the untreated base. Although with coatings of more than 50 mils (0.050-inch) thickness the particular base material used did not appreciably affect the flame spread index of the assembly, it appeared that with thinner finish coatings the base material had an important bearing on the flame spread results obtained. In cases where the coating is intended to be applied to a specified substrate, the surface flammability of the prescribed assembly is required. However, in cases where a particular substrate is not specified and a comparative evaluation of coatings only is desired, a suitable standard substrate material is required.

In choosing a standard substrate for paints, the use of an incombustible material such as asbestos cement board would obviously restrict the range of the flame spread index values and therefore the evaluation of the effectiveness of the paint film in reducing surface flammability. A study was therefore undertaken for measuring the surface flammability of a number of conventional paints and fire-retardant coatings as applied to common combustible building finish materials. The primary objects of the investigation were:

(1) to evaluate the effectiveness of typical fire-retardant and conventional coatings applied to several combustible substrates at various spreading rates,

(2) to evaluate those characteristics of the substrate material which were important in surface flammability measurements on painted assemblies, and

(3) to select, if possible, one substrate as a standard for paint flammability measurements.

Material and Preparation

Five fire-retardant and three conventional interior paint finishes were applied to each of four substrates: paper wallboard, plywood, fiberboard and tempered hardboard. The coatings were applied to the smooth finished side of each substrate. Table 1 lists and briefly describes the substrates and Table 2 gives the schedule employed in the preparation of these test assemblies. With the exception of coating systems 7, 7a, and 7b, the effective spreading rate employed in the preparation of the assemblies was 125 ft^2/gal (two coats at 250 ft^2/gal). This rate, unusually heavy for conventional paints, was fairly representative of the spreading rates commonly used and recommended for fire-retardant coatings. The paints consisted of two alkyd flat paints (Nos. 3 and 8), one latex water emulsion paint (No. 6), four fire-retardant paints (Nos. 1, 2, 4, and 5), and one coating system consisting of an intumescent fire-retardant main coat plus a supplemental top coat (No. 7). The fire-retardant paints selected were typical proprietary materials.

Table I

Substrate Materials

Symbol	Substrate	Thickness in.	Density lb/cu ft
A	Paper Wallboard-Factory Finished One side	3/16	35.0
B	Plywood-Douglas Fir, exterior grade	1/4	39.0
C	Fiberboard-Interior Insulating Board, Class D (factory-finished)	1/2	19.4
D	Hardboard- Tempered	1/4	67.6
E	Hardboard- Tempered	1/4	55.1

The first step in preparing the test assemblies was to coat the substrate boards, at a spreading rate of 450 ft^2/gal, with a white pigmented primer-sealer conforming to Federal Specification TT-P-56. After 72 hours the primed substrates, with the exception of those reserved for coatings 7, 7a and 7b, received two coats of the paint under test at 250 ft^2/gal per coat, allowing 72 hours between coats. Sample 7 consisted of a flat fire-retardant main coat at 250 ft^2/gal plus a supplemental gloss fire-retardant top coat at 250 ft^2/gal. Sample 7a received only one main coat at 350 ft^2/gal. Sample 7b was coated in the same manner as sample 7 but with spreading rates of 350 ft^2/gal and 500 ft^2/gal for the main and top coats, respectively. The coatings on samples 7, 7a and 7b were purposely varied to study the effect on flame spread behavior of different rates of spreading of the same paints.

Table 2. Coating Schedule

Coating System	Main Paint Coating				Supplemental Top Coat			Description
	Density	Color	No. of Coats	Spreading Rate	Density	No. of Coats	Spreading Rate	
	lb/gal			ft^2/gal	lb/gal		ft^2/gal	
1	11.9	Aqua	2	250	-	-	-	Fire-Retardant Paint
2	12.8	White	2	250	-	-	-	" " "
3	12.2	"	2	250	-	-	-	Flat Alkyd Paint
4	10.6	"	2	250	-	-	-	Fire-Retardant Paint
5	13.6	"	2	250	-	-	-	" " "
6	11.5	"	2	250	-	-	-	Styrene-Butadine (Latex) Water Emulsion
7	12.3	"	1	250	11.95	1	250	Main Coat-intumescent, resin-base, flat, fire-retardant coating. Top Coat-interior gloss fire-retardant paint.
7a	12.3	"	1	350	-	-	-	Same as 7 Main Coat
7b	12.3	"	1	350	11.95	1	500	Same as 7
8	12.1	"	2	250	-	-	-	Flat Alkyd Paint

Note: A primer-sealer (10.8 lb/gal density) was applied to all substrates, at a rate of 450 ft^2/gal, before coating

In another study of the effect of spreading rate, one flat alkyd (No. 3) and one latex water emulsion type (No. 6) were applied to a tempered hardboard substrate (E). The rates and film thicknesses are given in Table 3. These paints were applied directly (without primer-sealer) to the smooth substrate surface in a sufficient number of coats to obtain the desired effective spreading rate, allowing 24 hours between coats.

Table 3. Spreading Rates and Film Thicknesses for Two Conventional Paints Applied to Tempered Hardboard Substrate (E)

Number of Coats	Effective Spreading Rate	Paint Film Thickness	
		Computed*	Measured**
	ft^2/gal	mils	mils
1	900	0.6	0.3
1	500	1.1	1.2
1	250	2.1	1.6
2	125	4.2	4.4
3	60	8.8	8.5
6	30	18.	21.

* 530 divided by effective spreading rate; based upon one-third nonvolatiles by volume.

** Average for paints 3 and 6, based upon microscope measurements across smooth-sanded edge surface.

After the application of the finish materials, the assemblies were dried for not less than 72 hours and then cut to produce five specimens, each 6 by 18 inches. The specimens were then dried in an oven at 160°F for 24 hours and again conditioned, in a room maintained at 73°F and 50 per cent relative humidity, for not less than one week prior to testing. An alternate drying procedure, 24 hours at 140°F, was used for half of the test specimens prepared for the spreading rate study. However, no appreciable difference in the test results could be attributed to the effect of the slightly different drying procedure.

Test Procedure

The apparatus used for the tests is shown in Figure 1, and has been described in detail [2, 3]. It consists of a radiant panel, a frame for support of the test specimen, and associated measuring equipment.

The radiant panel consists of a cast iron frame enclosing a 12- by 18-inch porous refractory material. The panel is mounted in a vertical plane, and a premixed gas-air mixture supplied from the rear is burned in intimate contact with the refractory surface to provide a radiant heat source. The energy output of the panel, which is maintained by regulating the gas flow according to the indication of a radiation pyrometer, is that which would be obtained from a black body of the same dimensions operating at a temperature of 670°C. A stack placed under the hood above the test specimen receives the hot products of combustion and smoke.

For test, the 6- by 18-inch specimen was placed in a metal holder and backed with a 1/2-inch sheet of asbestos millboard of 60 pound per cubic foot density. At time zero, the specimen was placed in position on the supporting frame facing the radiant panel and inclined 30 degrees to it. A pilot igniter fed by an air-acetylene mixture served both to initiate flaming at the upper edge of the test specimen and to ignite combustible gases rising from the specimen. Observations were then made of the progress of the flame front, the occurrence of flashes, and so forth. An electrical timer calibrated in minutes and decimal fractions to hundredths was used for recording the time of occurrence of events during the tests. The test duration was 15 minutes, or until sustained flaming had traversed the entire 18-inch length of the specimen, whichever time was less.

The flame-spread index, I_s was computed as the product of the flame spread factor, F_s, and the heat evolution Q, thus

$$I_s = F_s Q$$

where:

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6-t_3} + \frac{1}{t_9-t_6} + \frac{1}{t_{12}-t_9} + \frac{1}{t_{15}-t_{12}}$$

The symbols $t_3 \ldots t_{15}$ correspond to the times in minutes from specimen exposure until arrival of the flame front at a position 3. . . 15 inches, respectively, along the length of the specimen. $Q=0.1\Delta\theta/\beta$, where 0.1 is an arbitrary constant, $\Delta\theta$ is the observed maximum stack thermocouple temperature rise, in degrees F, at any stage of combustion of the specimen minus the maximum temperature rise observed with an asbestos-cement board substituted for the specimen, and β is the slope of the line obtained by plotting the maximum stack thermocouple temperature rise as a function of the corresponding measured heat input rate, in Btu per minute, as supplied by a diffusion-type gas burner placed near the top of an asbestos-cement board specimen during normal operation of the radiant panel.

Results and Discussion

A minimum of four replicate tests were run on each test assembly. The mean flame spread indices and the coefficients of variation are listed in Tables 4 and 5. The weight of the smoke deposit listed is the mean for replicate tests. Although not directly related to surface flammability, the smoke deposit is considered to be an indication of possible parallel hazards, such as toxicity and the interference to be expected in evacuation and fire-fighting procedures. The smoke deposit values represent the contribution of both the coating and substrate materials as evidenced by the somewhat higher mean smoke deposits for coatings on hardboard (D) than on the other substrates. The fire-retardant coatings tested did not produce significantly greater smoke deposits than the conventional paints.

Intumescence was exhibited by paints 1, 7a, and 7b. Paints 2, 4, 6, and 7 blistered, whereas the alkyd paints 3 and 8 did not blister or intumesce. Paint 5 flaked off from the substrate during test. Blister and intumescent formations were responsible for a wide variation in flame spread indices for the paints which exhibited these properties.

Of the four substrates used, the plywood and the hardboard showed the widest range in flame spread index values, affording good opportunity for discrimination between coatings. The hardboard values, however, had lower coefficients of variation than the plywood values, and much lower than those obtained with the other two substrates. Considering the results obtained with the hardboard, the conventional paints 3, 6, and 8 appeared to be comparable to the fire-retardant paints 1, 4, and 5, when applied to this substrate at the same effective spreading rate of 125 ft^2/gal. The intumescent fire-retardant coating, 7a, showed both the lowest flame spread index and the lowest smoke deposit value of any of the coatings.

At effective spreading rates of 250 ft^2/gal or greater, the flame spread index was found to be strongly affected by the spreading rate as shown in Figure 2. One coat of a flat alkyd paint applied at a rate of 250 ft^2/gal reduced the flame spread index of a tempered hardboard substrate by a factor of almost 5. Similarly, a coat of a latex paint effected a more than three-fold reduction. For film thicknesses greater than those corresponding to 250 ft^2/gal, the additional improvement in flame spread index was quite small. The effect of very thick films, such as might be encountered on surfaces frequently repainted, was not investigated. It is possible, however, that a higher flame spread index might result from the formation and disintegration of blisters, from cracking, peeling or other separation from the flammable substrate, or by the direct involvement of the thick paint layer.

The effect of paint thickness upon surface flammability properties refers only to typical combustible cellulose-base substrates in contrast to non-combustible substrates such as plaster, concrete or metal.

Table 4. Mean Flame Spread Index and Mean Smoke Deposit of Coated Assemblies Based on Four Replicate Tests

	SUBSTRATE											
	A Paper Wallboard			B Plywood			C Fiberboard			D Hardboard		
Coating System	Mean I_s	Coeff. of Var.[a]	Mean Smoke	Mean I_s	Coeff. of Var.	Mean Smoke	Mean I_s	Coeff. of Var.	Mean Smoke	Mean I_s	Coeff. of Var.	Mean Smoke
		%	mg		%	mg		%	mg		%	mg
Uncoated Substrate	126	11	-	167	7	0.3	83	16	0.2	150	9	2.6
1	44	48	2.5	21	85	3.1	35	115	3.1	29	39	4.1
2	48	37	1.5	75	25	1.7	17	96	1.0	75	21	4.5
3	20	56	1.1	27	6	1.4	7	62	0.7	28	15	5.0
4	34	62	2.6	34	21	2.2	18	71	1.9	37	5	3.6
5	9	55	1.6	14	42	2.6	6	70	1.6	33	7	4.9
6	60	39	2.2	46	60	2.8	15	101	2.5	42	25	5.1
7	8	64	2.1	9	69	2.7	9	103	1.4	40	54	3.2
7a	1.2	86	1.3	2	71	1.8	1.2	151	1.5	1.5	73	1.2
7b	9	183	1.6	7	94	1.5	9	96	1.9	6	54	1.9
8	46	30	1.0	42	76	1.4	13	54	0.9	28	15	3.9

[a]Defined as the ratio of the standard deviation to the average, expressed as a percentage

Table 5. Mean Flame Spread Index of Two Conventional Paints at Varying Spreading Rates Applied to Tempered Hardboard

Paint	Effective Spreading Rate	Number of Tests	Mean Flame Spread Index	Coeff. of Variation	Mean Smoke Deposit
	ft^2/gal			per cent	mg
Uncoated Substrate	-	4	116	8	2.1
Alkyd Flat No. 3	900	4	58	13	2.4
	500	4	52	11	2.4
	250	4	24	13	2.7
	125	4	20	4	2.4
	60	4	13	8	2.4
	30	5	27	72	1.7
Latex No. 6	900	4	94	2	2.6
	500	5	30	25	2.0
	250	4	35	9	1.8
	125	4	42	24	2.0
	60	5	37	10	2.7
	30	5	32	91	3.4

In another study, in which non-flammable substrates were used, it was found that the flame spread index increased with increasing thickness of a paint coating applied on steel sheet. For example, the flame spread index of a No. 18 gage, red lead primed steel sheet had values of 1, 7, 69, and 110 for oil-base paint coatings of 5, 10, 15, and 20 mils, respectively. An assembly of a 10 mil coating of the same paint applied to 1/8-inch thick asbestos-cement board had a flame spread index of 2. Thus it appears evident that the flame spread behavior of coatings applied to either flammable or non-flammable substrates depends not only on the type and thickness of the paint film but also on the characteristics of the substrate.

For a conventional paint, such as flat alkyd (No. 3) applied at an effective spreading rate of 125 ft^2/gal, the ratio of the flame spread index of the painted assembly to that of the substrate was found to be related to the density of the substrate material. The effect at other spreading rates was not explored. As shown in Figure 3, this paint was most effective on the low density fiberboard substrate. A majority of the other paints tested were also most effective on the low density substrate. However, for critical evaluation of a paint for fire-retardancy, the burden of effective performance should be placed upon the paint without ascribing to the paint undue advantage resulting from the properties of the substrate. For this reason, tempered hardboard is considered a more suitable substrate.

An analysis of the data was made to provide a statistical measure of variability. Particular attention was directed toward evaluation of the substrate materials both from the standpoint of (a) selection of a standard material for paints and other liquid coatings and (b) interpretation of previous and subsequent flame spread data on coated assemblies employing a variety of substrates.

The analysis showed that although the wallboard and fiberboard substrates gave a more consistent behavior of dispersion about the mean than the plywood and hardboard substrates, the coated hardboard assemblies did exhibit:

a. A substantial range of flame spread index values for the coating materials, and

b. The lowest coefficients of variation.

It should be noted that considerable variation was observed in the rankings of the coatings on the four substrates. In addition, the coefficients of variation were considerably higher than those obtained in an earlier investigation of conventional paints on the same or similar substrates [1]. This is not unreasonable when consideration is given to the special types of coatings and rates of application employed here. Inasmuch as the hardboard did result in the lowest coefficient of variation and provided a substantial range of flame spread index values for the coating materials tested, its choice as a standard substrate is indicated.

Conclusions

On the basis of the work reported, the following conclusions seem justified:

1. Tempered hardboard may be considered a suitable choice as a standard substrate for evaluating the fire-retardant effectiveness of paints and other thin surface coatings. Of the substrates studied, it gave results with the lowest coefficient of variation, provided a substantial range in flame spread index values for the coating materials tested, and placed the burden of effective performance upon the paint under test.

2. The fire-retardant effectiveness of paints and other coatings is highly dependent upon the effective spreading rate of the paint and on the type and density of the substrate material, as well as on the coating composition and the undercoat-overcoat combination employed. Coatings of latex and flat alkyd paints applied to a tempered hardboard substrate at an effective spreading rate of 250 ft^2/gal reduced the flame spread index of the uncoated substrate by factors of 3 and 5, respectively.

3. In general, conventional paints of the flat alkyd and latex emulsion types tested, when applied at the heavy rate common for fire-retardant coatings, appear to have flame spread indices comparable to those of the fire-retardant coatings. However, one intumescent fire-retardant coating showed a flame spread index significantly lower than that of any other tested.

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References

(1) Gross, D., Loftus, J. J., Flame Spread Properties of Building Finish Materials, Am. Soc. Testing Mats., Bul. No. 230, 56-60, May 1958.

(2) Interim Federal Standard No. 00136 (Comm-NBS) July 31, 1959

(3) Robertson, A. F., Gross, D., Loftus, J. J., A Method for Measuring Surface Flammability of Materials Using a Radiant Energy Source, Proceedings, Am. Soc. Testing Mats., 56, (1956).

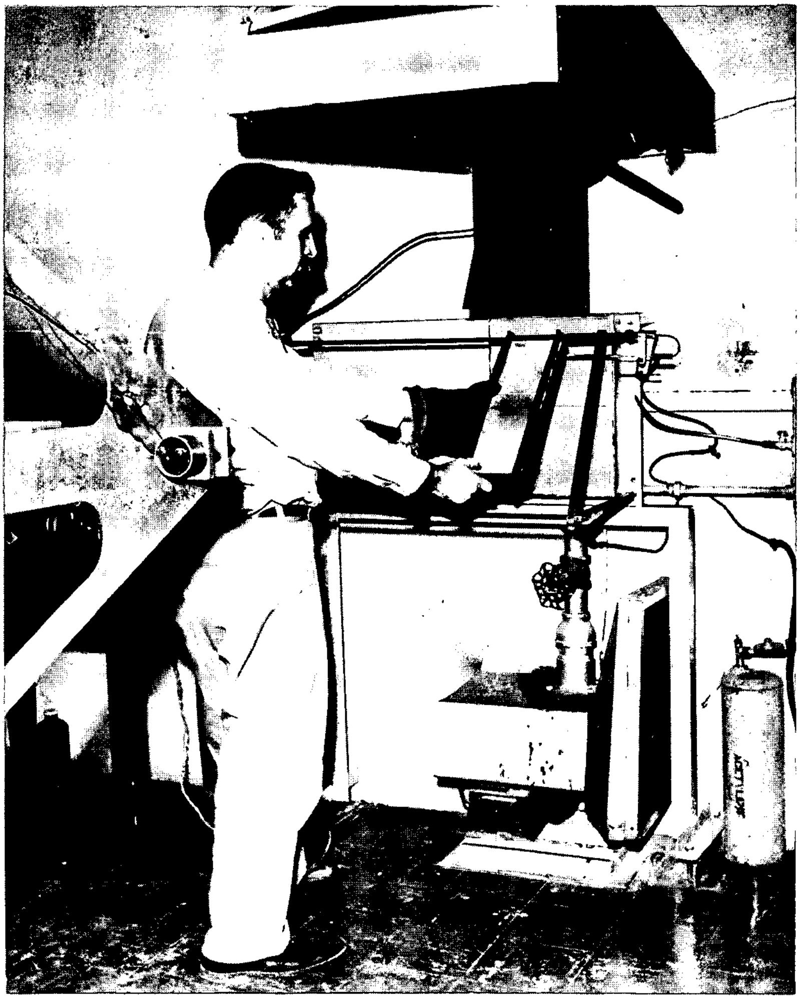

FIG. 1 - RADIANT PANEL TEST APPARATUS

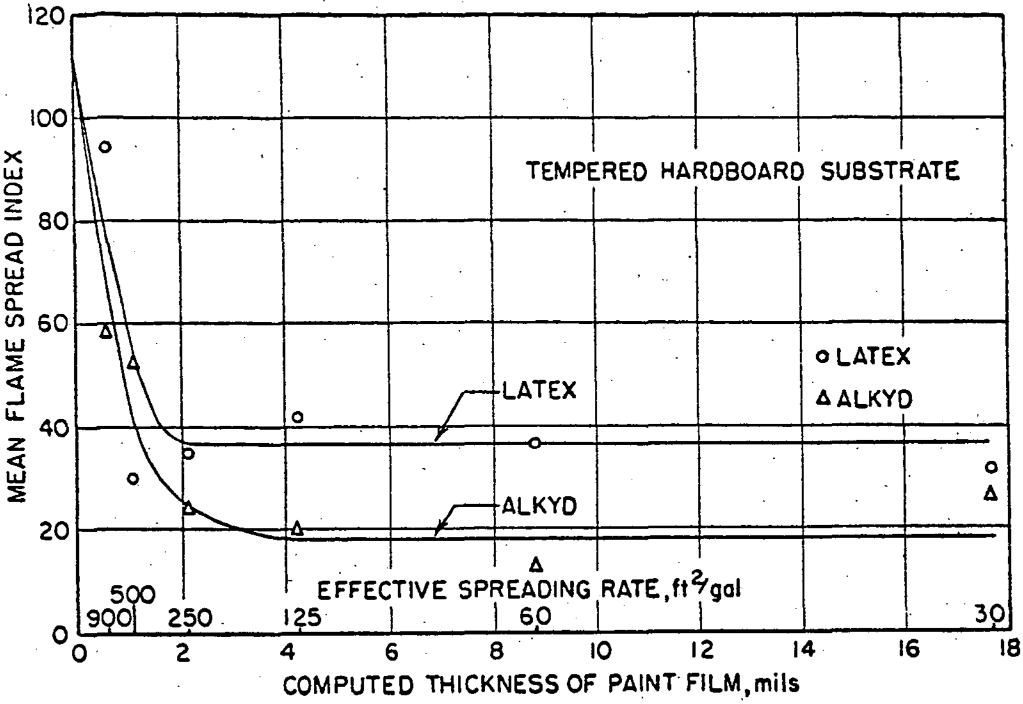

FIG. 2 - EFFECT OF PAINT FILM THICKNESS ON MEAN FLAME SPREAD INDEX FOR TWO CONVENTIONAL PAINTS

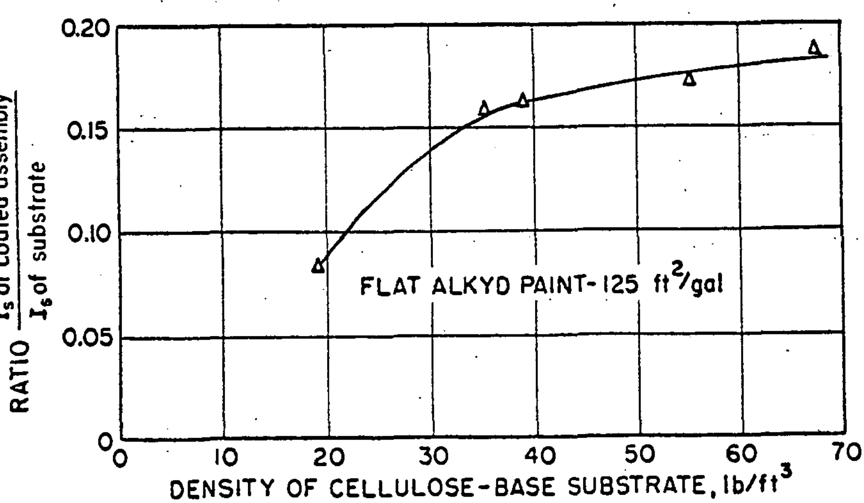

FIG. 3 - EFFECT OF SUBSTRATE DENSITY UPON FLAME SPREAD INDEX RATIO